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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

SOVIET ROCKETS AND ROCKET ENGINES

by

Ernő Nagy

FOREIGN TECHNOLOGY DIVISION

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By: Ernő Nagy

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ABSTRACT

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The RD-107 Soviet rocket engine is used in the first and second stages of the Vostok rocket. It operates on a kerosene-oxygen mixture and reaches a discharge velocity close to 3100 m/s. The RD-119 engine, using dimethlhydrazine and liquid oxygen, ~~and~~ has a discharge velocity of 3450 m/s and is used also in the upper stage of Kosmos boosters. The trend of development is towards greater specific impulse and greater discharge velocity. Dr. N. Melik Pashayev, one of the Soviet rocket experts, maintains that an increase of the specific impulse from 250 kp.s/kp to 300 kp.s/kp - for the same payload and the same task leads to a reduction of the booster's initial weight by one half; when the specific impulse is increased from 250 kp.s/kp to 400 kp.s/kp, the initial weight is reduced to one-fifth of the original weight. This explains the interest in the development of hydrogen-oxygen engines.

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SOVIET ROCKETS AND ROCKET ENGINES

Ernő Nagy

During the second trimester of 1967, the citizens of many European nations, including those of Hungary, were given the opportunity to view the Vostok carrier rocket and obtain a firsthand impression of this masterpiece of Soviet engineering. It is primarily the importance of the Vostoks, rather than the anniversary celebrations, which has prompted us to discuss their design and evaluate their role in the development of rocket engineering.

The Propellant Problem

The two factors which most influence the performance of a rocket are the energy content of the propellant and the design of the rocket. One propellant performance parameter is the exhaust velocity of combustion gases. An alternate measure of performance is the impulse obtained per kg of propellant used (kg/s). Another way of expressing this is the kgf of thrust obtained per kg/s of propellant flow. As for the structural design of a rocket, it is an engineering problem whose successful solution makes it possible to obtain a large useful load (spacecraft, instrumentation, and, primarily, propellant) and a minimum of deadweight.

Because of its influence on many rocket components, the first subject to be discussed in depth will be the selection of a propellant.

There has been a great deal of speculation about the type of propellant used by Soviet booster rockets. A great deal has been written and said about "miracle propellants." In an earlier article, we explained that the extensive use of "exotic" propellants is extremely unlikely — especially, in the present phase of space research. A Vostok booster rocket consumes approximately 280 to 300 tons of propellant, which must be of uniform quality and stored in the tankage system at lift-off. This requirement alone excludes the possibility of introducing exotic materials since an entirely new industry would have to be developed in order to produce the thousands of tons of propellant required every year.

GRAPHIC NOT REPRODUCIBLE

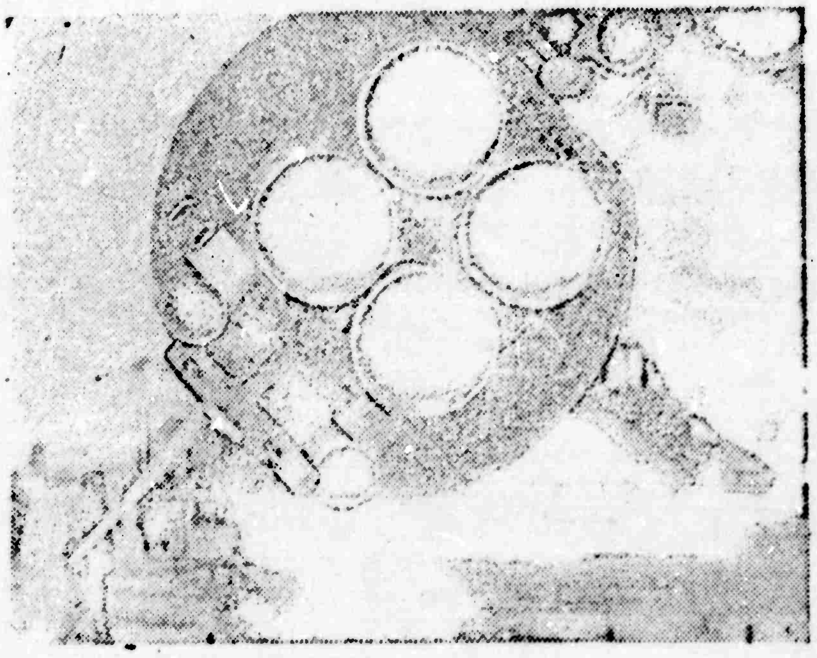
The second stage of the Vostok rocket.

GRAPHIC NOT REPRODUCIBLE

The Vostok rocket on a track-guided transporter-elevator at the Paris exhibit.

In fact, both jet aircraft and rockets use a hydrocarbon, namely, kerosene, as their fuel. This substance can be produced in huge quantities without sacrificing quality; furthermore, it is storable, and feed systems for its transfer to the thrust chamber have been developed. Thus, it should come as no surprise that the Vostok booster rocket is also powered by kerosene. The RD-107 engine (used in the first and second stages) develops a specific impulse of 314 kgs/kgf or an exhaust velocity of approximately 3100 m/s (i.e.; above 20 km altitude in a vacuum). This means that the selection of this propellant was not a 100% logical decision. However, its thermal efficiency is very high.

GRAPHIC NOT REPRODUCIBLE



The RD-107 engine and two control nozzles used in the Vostok 1st stage.

The trend in development is indicated by the fact that the RD-119 engine uses a propellant combination of dimethlhydrazine and liquid oxygen. (This engine is used by the upper stages of several Kosmos booster rockets presently displayed in Moscow.) Its specific impulse is 352 kgs/kgf and its exhaust velocity is 3450 m/s. Clearly, the trend is toward greater specific impulse and greater exhaust velocity. According to Dr. N. Melik-Pashayev, a Soviet rocket expert, the booster's lift-off weight can be cut in half by increasing the specific impulse from 250 kgs/kgf to 300 kgs/kgf without varying the payload or the mission. On the other hand, if the specific impulse

is increased from 250 kgs/kgf to 400 kgs/kgf, the lift-off weight is reduced to one-fifth of the original weight. This accounts for the great interest in hydrogen-oxygen engines. It is very likely that the Soviets have already tested these engines in recent launch vehicle experiments. They may have even been used in space probes, mainly in the upper (second and third).

In view of the above, the propellant performance rating is far from unfavorable. In fact, it can be concluded that after weighing all the important factors, such as performance, cost, and manufacturing ease, Soviet rocket engineers have selected the best possible propellant. It is not the sensational, but the logical solution which promotes technical development...

Engines

The use of multiple chambers in Soviet rockets was the product of a great deal of hard work. The RD-107 engine has four combustion chambers and four propulsion nozzles. Stability and control are provided by two relatively large control nozzles with an estimated thrust of 4-4.5 tons (there are two such control nozzles on each strap-on and four on the inner stage). In a vacuum of 102 tons, each engine cluster; i.e., each propulsion nozzle, develops as much thrust as a V-2 engine.

Since the highest specific impulse hitherto acknowledged for a kerosene-oxygen mixture is 280-300 kgs/kgf, the significantly greater specific impulse of the RD-107 engine (315 kgs/kgf) indicates that its thermal efficiency is also greater (70% as opposed to the usual 60%). This was achieved in part by raising the combustion chamber pressure to a relatively high value of 60 at. Thus, thermal efficiency is increased as chamber pressure is increased. The expansion ratio has also been increased (to 150:1), as a result of which more propellant is converted into energy.

Under these conditions, the natural course of action is to replace the single, large chamber with four smaller ones. An advantage

of smaller, cylindrical chambers is that it is easier to meet strength requirements when they are used. This is a fact that is already known in chemical engineering and mechanics. However, this is not its only salient feature, for it is also much easier to cool several small areas than one large area.

The total cooling surface of the four small chambers is approximately 60% greater than that of a single, larger combustion chamber (which is of uniform volume). Furthermore, losses due to incomplete combustion are reduced. Since temperatures in the order of 3000C° reign in the chambers, both the cooling surfaces and the regenerative cooling system perform important functions.

Regenerative cooling is accomplished with the aid of the propellant which, in this case, is kerosene. The latter enters the cooling jacket through a pipe measuring 4.5 cm in diameter and located at a distance of 18 cm from the nozzle exit. As it is circulated throughout the engine, it removes heat from the walls.

While the RD-107 employs conical nozzles, which sustain relatively great energy losses (total energy conversion cannot be obtained unless expansion occurs in a vacuum), the nozzles of RD-119 engines are much longer. Since these engines are used in the upper stages of launch vehicles, the gases expand in a vacuum. Combustion chamber pressures, which are in the order of 80 at, are higher than those of any other rocket engine. These high pressures contribute greatly to the superior performance of dimethlhydrazine since, under normal conditions, its performance level does not differ significantly from that of kerosene. In view of the above, it should come as no surprise that the expansion ratio is 1330:1 and the final pressure of expansion in the long, bell-shaped (Prandtl) nozzle is very low. Here again, temperature control is obtained through regenerative cooling.

Structural Design of Rockets

This brings us to the subject of structural design. The Vostok rocket is also outstanding in this respect. This is indicated by the fact that Vostoks carried the large Molniya and Meteor satellites into

orbit. Improved and modified versions were used to launch certain Kosmos-series satellites and Voskhod spacecraft. The smaller Kosmos satellites were launched by two-stage boosters – some of which are on display in Moscow. Classic staging configuration is employed in this type of rocket, which bears a close resemblance to intercontinental missiles seen in large military parades. An engine similar to the RD-107 is employed in the first stage, while, in some cases, the upper-stage engine is similar to the RD-119.

The use of parallel staging; i.e., an arrangement in which four units of the first stage are placed around the second stage, of the Vostok rocket amazed the entire world, even though this scheme is the most logical one. Furthermore, it is critical to the stability of a long, slender body in motion in air, such as a rocket. With parallel staging, the first stage does not increase the height of a rocket (which, if staging in series were used, would be 60 m high); instead, it reduces its height and lowers its center of gravity. Consequently, stability is enhanced, which is particularly important in the case of manned flights.

The burning duration of each Vostok stage can be obtained by determining the mass of each. Accordingly, the four rockets of the first stage are expended after operating for 2.5 minutes. On the other hand, the inner, second stage, which ignites simultaneously with the first stage, continues to function for another 3 minutes, so that its burning duration is 5.5 minutes. Separation of the four units of the first stage is a simple procedure which is accomplished with the aid of explosion bolts. Subsequent to lift-off, a maximum acceleration of 5 g is attained. From the standpoint of acceleration, the critical phase is reentry, when negative acceleration approaches values of 10 g.

In our consideration of the Vostok booster rocket, we must not lose sight of the fact that it is at least ten years old. It was designed in 1957, and by 1960 it was participating in space-flight tests. On April 12, 1961, Gagarin began the first manned space flight in a spacecraft carried aloft by a Vostok rocket. The Voskhod booster, which consists of a 50-ton stage and delivers 650 tons of thrust, was developed from it.

To date, the largest booster rockets are the ones which lifted the Proton and Soyuz vehicles into orbit. The power rating of this type of rocket is 60 million horsepower. To give the power rating of rockets and jet engines is somewhat misleading (actually, thrust remains at a nearly constant value, while velocity and power increase steadily); nevertheless, it is apparent, that the power of a Voskhod rocket is three times greater than that of a Vostok. The dimensions of the final stage can be learned by studying those of the Proton satellite since the latter is covered by the shroud of the last stage (the solar paddles are tucked behind the nose cone). Its diameter is 5 meters, which is twice that of the Vostok final stage. The Soviet Union owes its great success in space research to the development of outstanding booster rockets.